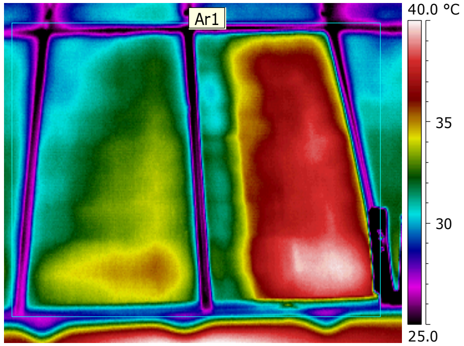
SAND2018-2121C



PV Component Reliability Distributions – Database and Insights

2018 PV Reliability Workshop

Geoffrey T. Klise, Olga Lavrova, Renee Gooding
Sandia National Laboratories
Janine Freeman, Andy Walker
National Renewable Energy Laboratory

March 1, 2018

SAND2018-XXXXC

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Outline

- What kind of data are we collecting?
- Summary of reliability database
- Portfolio A (utility-scale)
- Portfolio B (DG)
  - Failure and Repair Distributions – insights into events and maintenance response
- Where the data can be used
  - SAM PV-RPM feature
  - O&M Cost Model

PV System Data – DG and Utility-Scale

Maintenance Data	Performance Data	System Data
Specific Component	Energy production	Engineering and one-line diagrams
Fault or failure timestamp	Energy loss	Commissioning date
Repair timestamp	Performance model estimates	Component manufacturer and model/make detail
Equipment replaced		
Repair under warranty		
Fault Code (inverter)		
Narrative description (*relationship to other components or external events*)		
Quarterly maintenance reports		

Reliability Database

Data compiled and analyzed up through December 2017

Portfolio	Commissioning year	Data collection range	Number of PV systems	MW_{DC}	% of DG systems	% of utility scale systems
A	2003	2003-2008	1	3.5	0	100
B	2008-2009	2012-2014	2	1.75	100	0
C	2008-2016	2015-2016	180	578	3.4	96
D	2010-2017	2013-2017	61	25.6	100	0

A – 1 - Collins, E., M. Dvorack, J. Mahn, M. Mundt, and M. Quintana, 2009, *Reliability and Availability Analysis of a Fielded Photovoltaic System*, Presented at the 34th IEEE PVSC, 7-12 June 2009, Philadelphia, PA.

2 - Klise, G.T., O. Lavrova and J. Freeman, 2017, *Validation of PV-RPM Code in the System Advisor Model*, SAND2017-3676, April 2017.

B – Klise, G.T., R.R. Hill, C.J. Hamman, P.H. Kobos, V. Gupta, B.B. Yang, and N. Enbar, 2014, *PV Reliability Operations and Maintenance (PVROM) Database Initiative: 2014 Progress Report*. SAND2014-20612, December 2014.

C – Klise, G.T., O. Lavrova, R. Gooding, J. Freeman and A. Walker, *Improved Performance Modeling that Reflects Component Reliability Metrics*, 2017 NREL/SNL/BL PV Module Reliability Workshop, March 2, 2017.

D – Klise, G.T., O. Lavrova and R. Gooding, 2018, *PV System Component Fault and Failure Compilation and Analysis,* SAND2018-1743, February 2018.

Reliability Database

Data compiled and analyzed up through December 2017

Portfolio	Commissioning year	Data collection range	Number of PV systems	MW_{DC}	% of DG systems	% of utility scale systems
A	2003	2003-2008	1	3.5	0	100
B	2008-2009	2012-2014	2	1.75	100	0
C	2008-2016	2015-2016	180	578	3.4	96
D	2010-2017	2013-2017	61	25.6	100	0

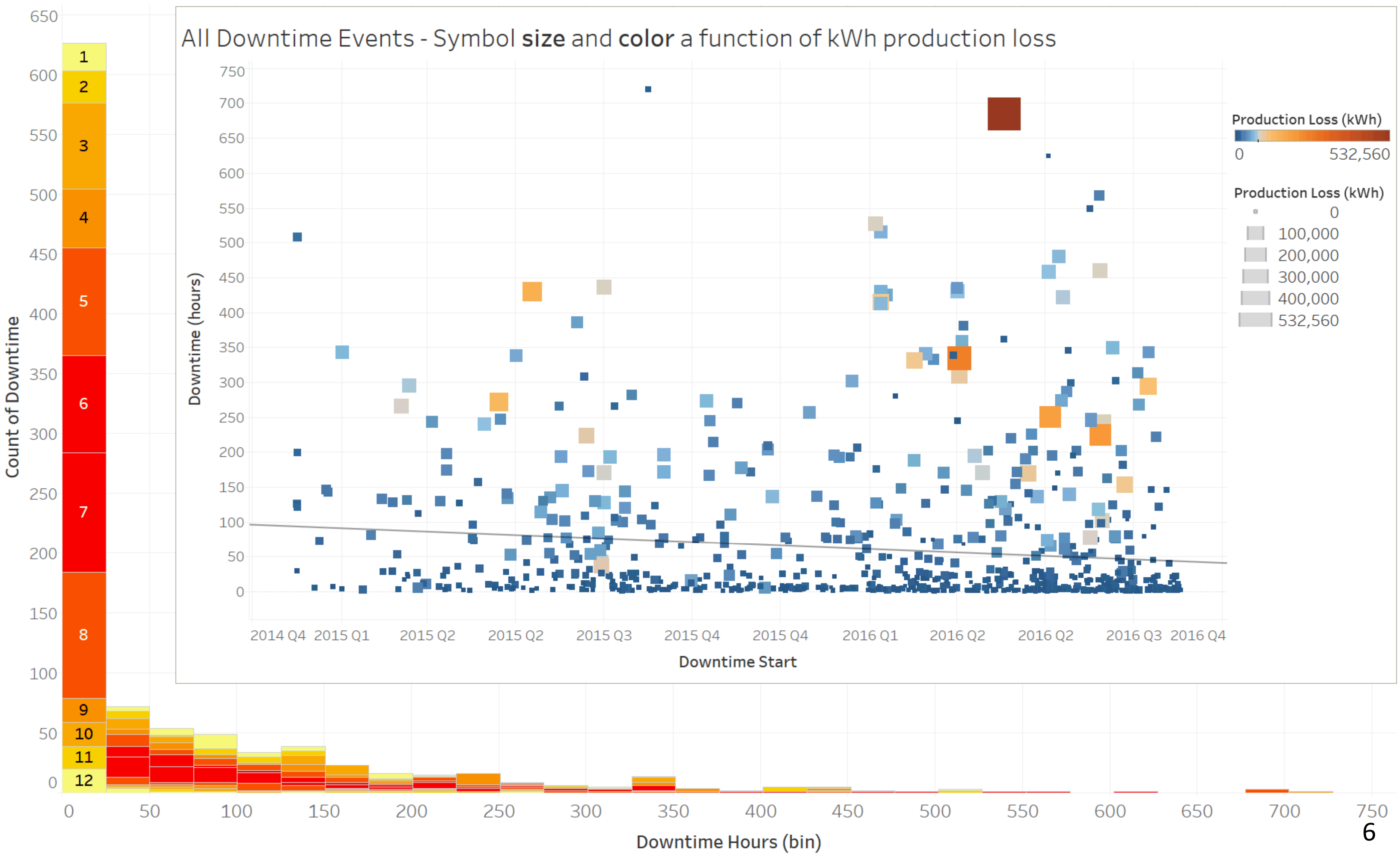
C – Klise, G.T., O. Lavrova, R. Gooding, J. Freeman and A. Walker, *Improved Performance Modeling that Reflects Component Reliability Metrics*, 2017 NREL/SNL/BL PV Module Reliability Workshop, March 2, 2017.

Portfolio C

Sandia National Laboratories

All Inverter Downtime - Frequency and Trend

Distribution of Downtime Events - Red colors represent **peak production months**



Reliability Database

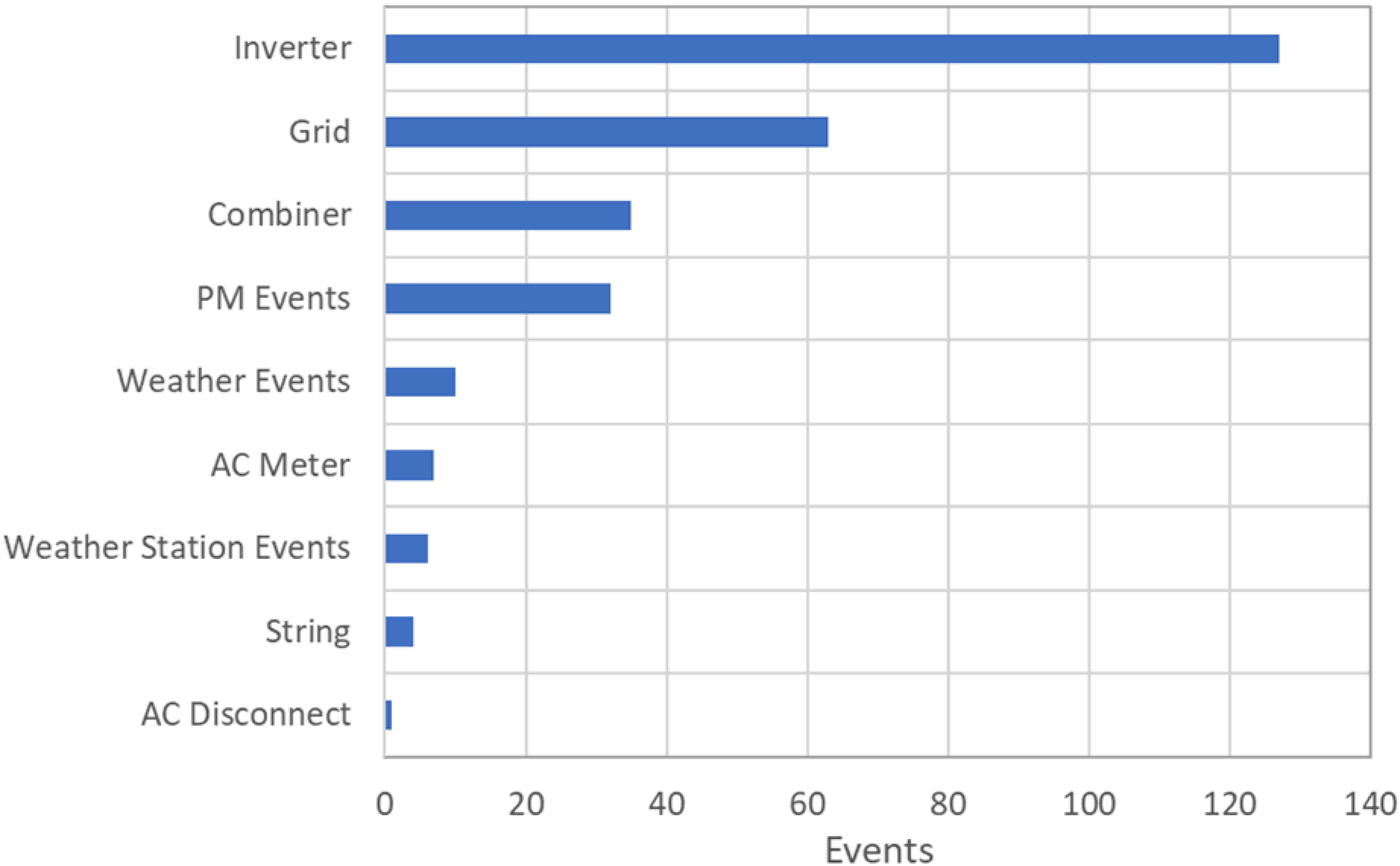
Data compiled and analyzed up through December 2017

Portfolio	Commissioning year	Data collection range	Number of PV systems	MW_{DC}	% of DG systems	% of utility scale systems
A	2003	2003-2008	1	3.5	0	100
B	2008-2009	2012-2014	2	1.75	100	0
C	2008-2016	2015-2016	180	578	3.4	96
D	2010-2017	2013-2017	61	25.6	100	0

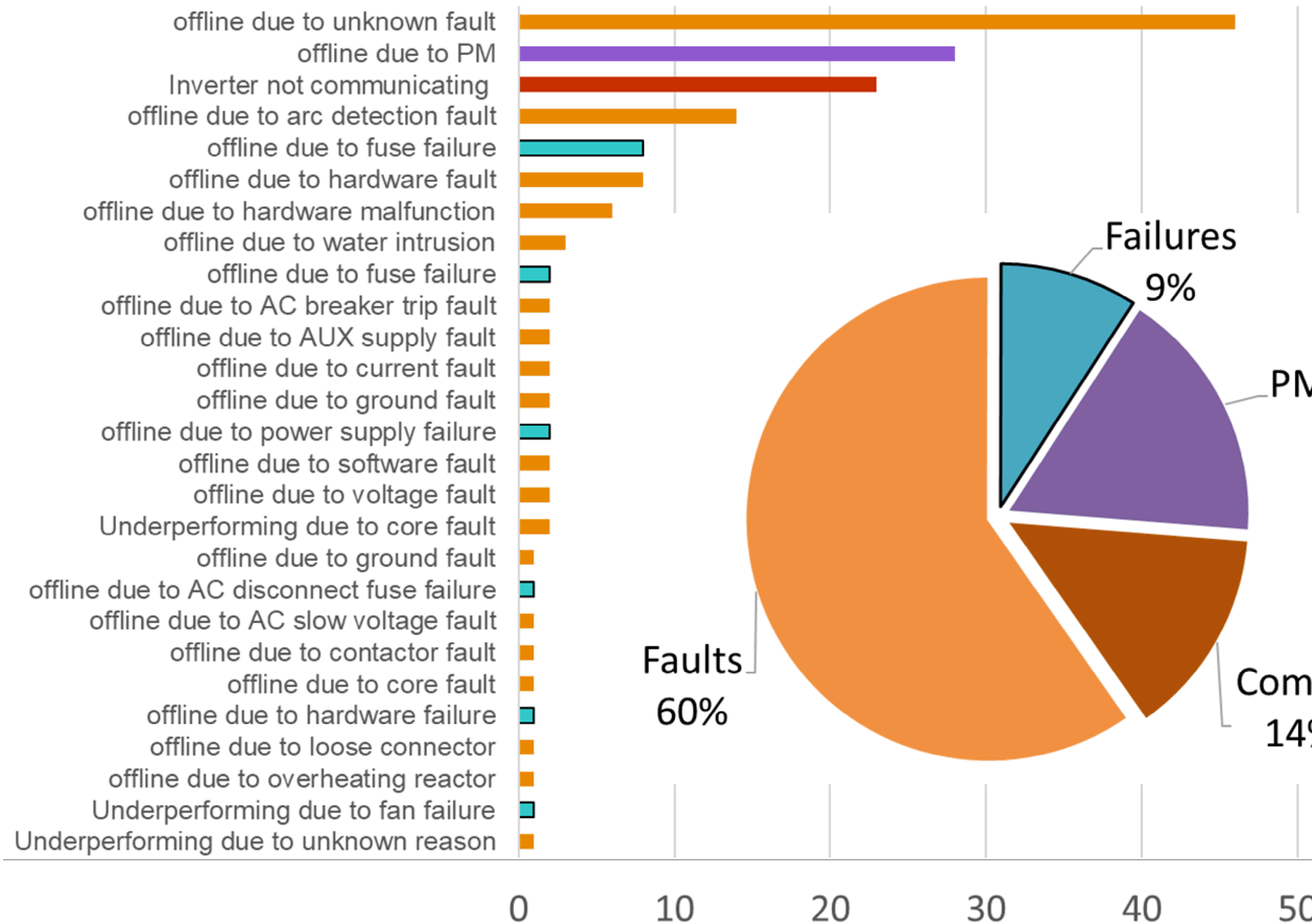
Portfolio	Unique module mfrs.	Unique module models	Total number of modules	Unique inverter mfrs.	Unique inverter models	Total number of inverters
D	11	25	83,891	8	29	129

D – Klise, G.T., O. Lavrova and R. Gooding, 2018, *PV System Component Fault and Failure Compilation and Analysis*, SAND2018-1743, February 2018.

Portfolio D – Event Summary



Portfolio D – Breakdown of Events that Tripped Inverters

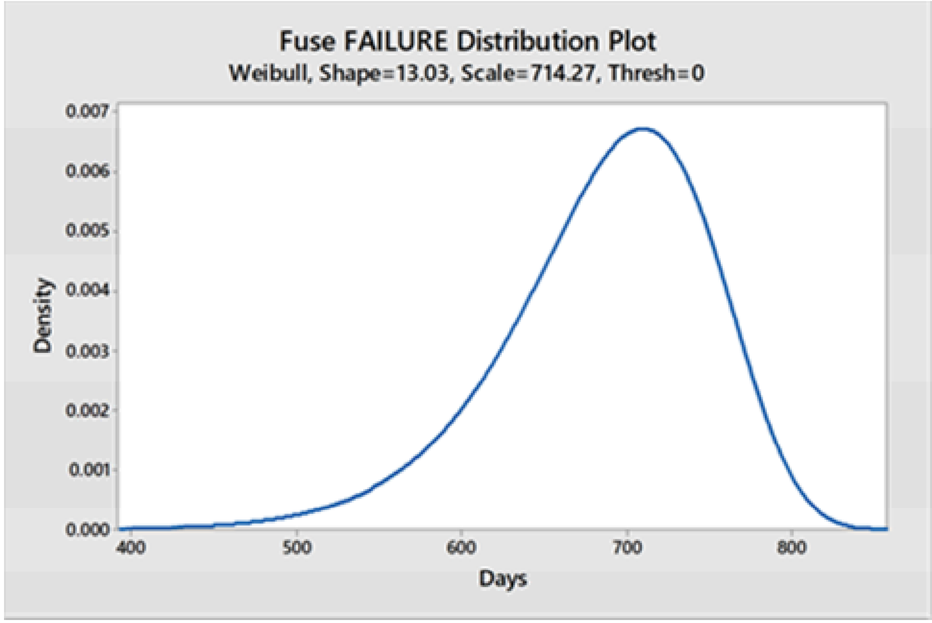


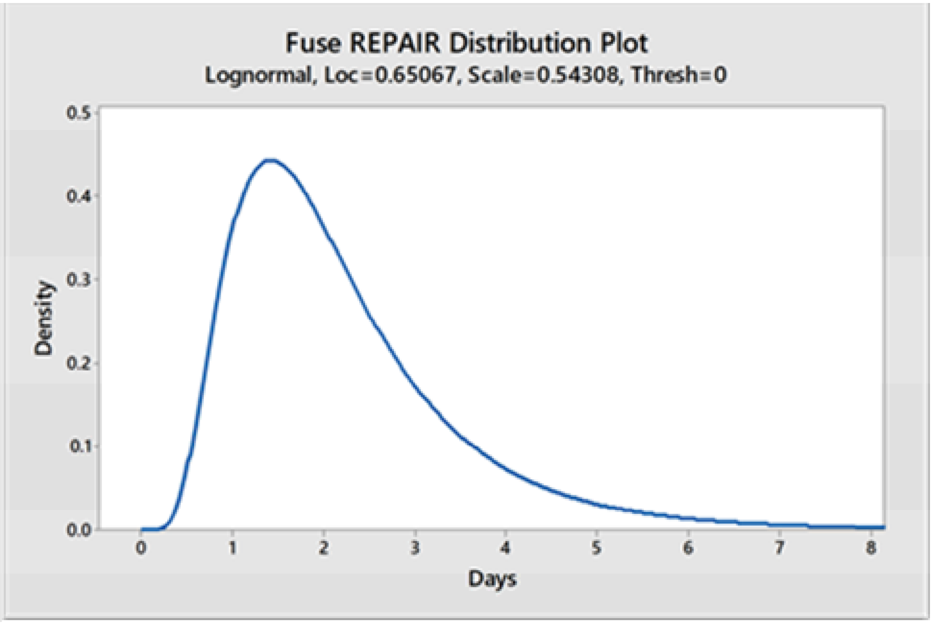
Portfolio D

- Fuse failure at inverter
- DC side arc fault – Trips inverter
- Recloser trip – grid event

			Fault/Failure Distribution				Repair Distribution			
Example	**Component & Location**	**Failure Type**	**Type**	**Shape / Mean**	**Scale / Stdev.**	**Time Unit**	**Type**	**Mean**	**Stdev.**	**Time Unit**
1	One Inverter at a site in the Eastern U.S.	Fuse failures	Weibull-2	13.03	714.27	day	Lognormal	0.6507	0.5431	day
2	One Inverter at a site in the Eastern U.S.	Tripping and resetting due to arc faults	Normal	256.979	148.56	day	Lognormal	-0.1181	1.3368	day
3	One Site in the Eastern U.S.	Recloser tripping on grid side	Weibull-2	1.36296	332.93	day	Lognormal	-1.7275	1.1695	day

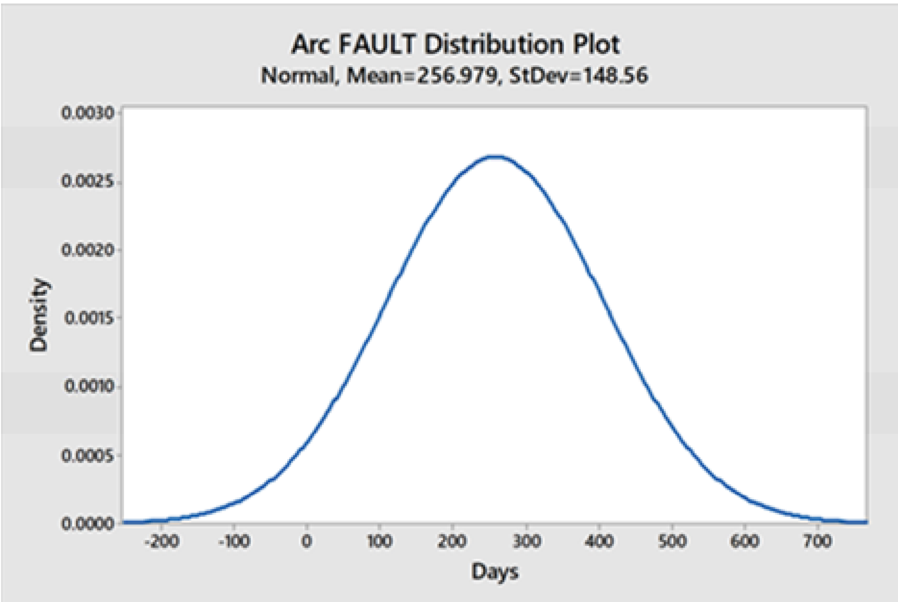
Fuse failure at inverter – failure and repair distribution

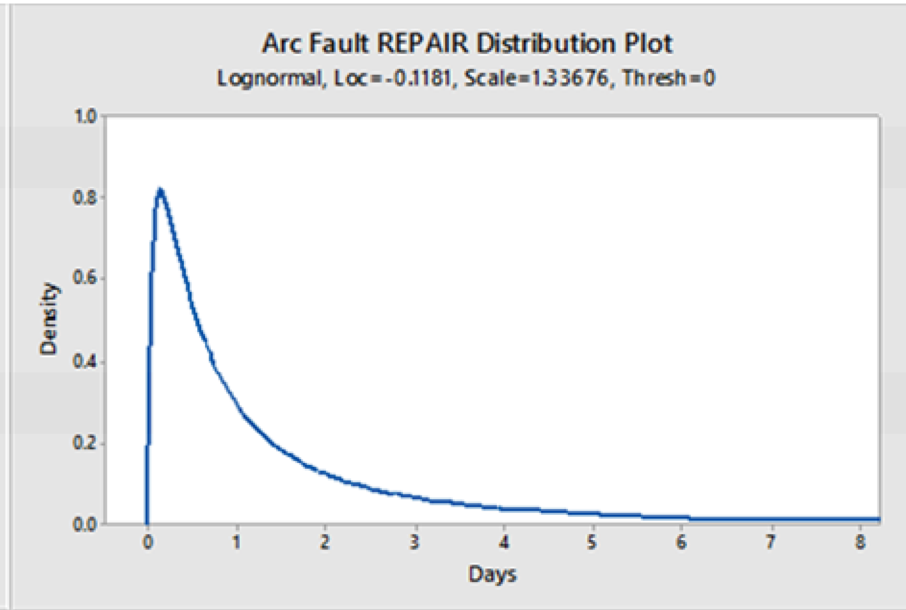




- Highest probability of fuse failure at 700 days
- Highest probability fuse will be replaced around 1.5 days. Only 20% chance the repair will happen three days after the event

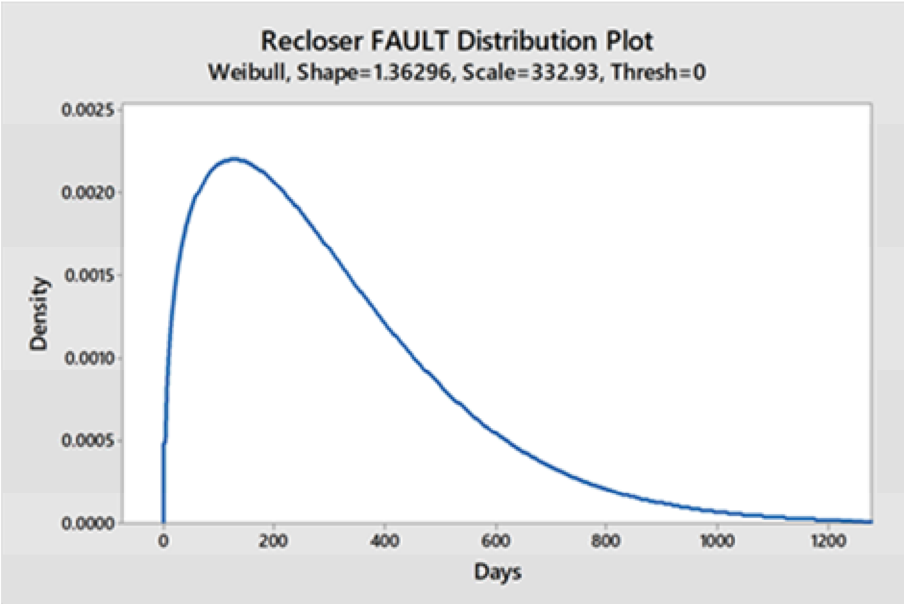
DC side arc fault – inverter fault and repair distribution

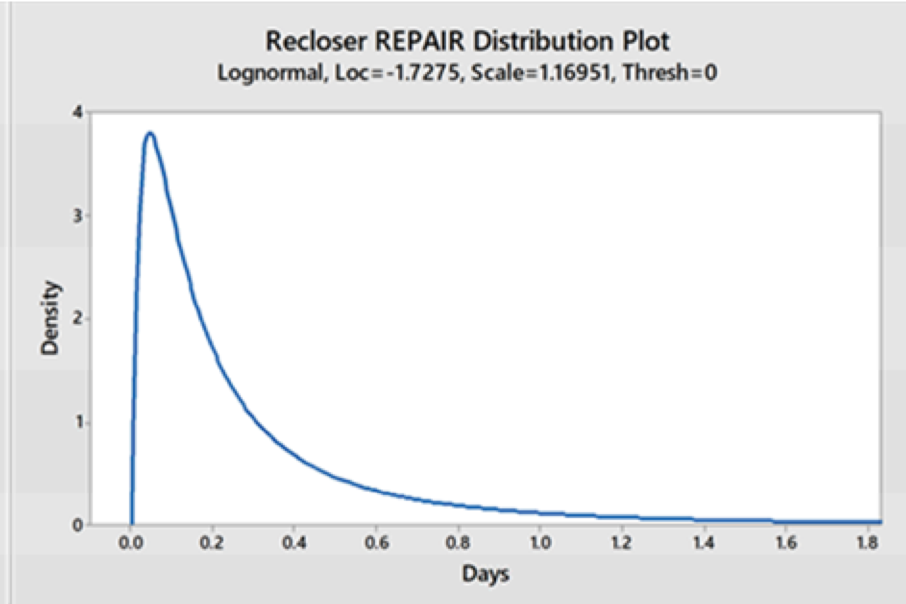




- Highest probability of arc fault event tripping the inverter at 300 days
- Highest probability inverter will reset at 0.15 days (~4 hours). Repairs happening later suggest manual restart

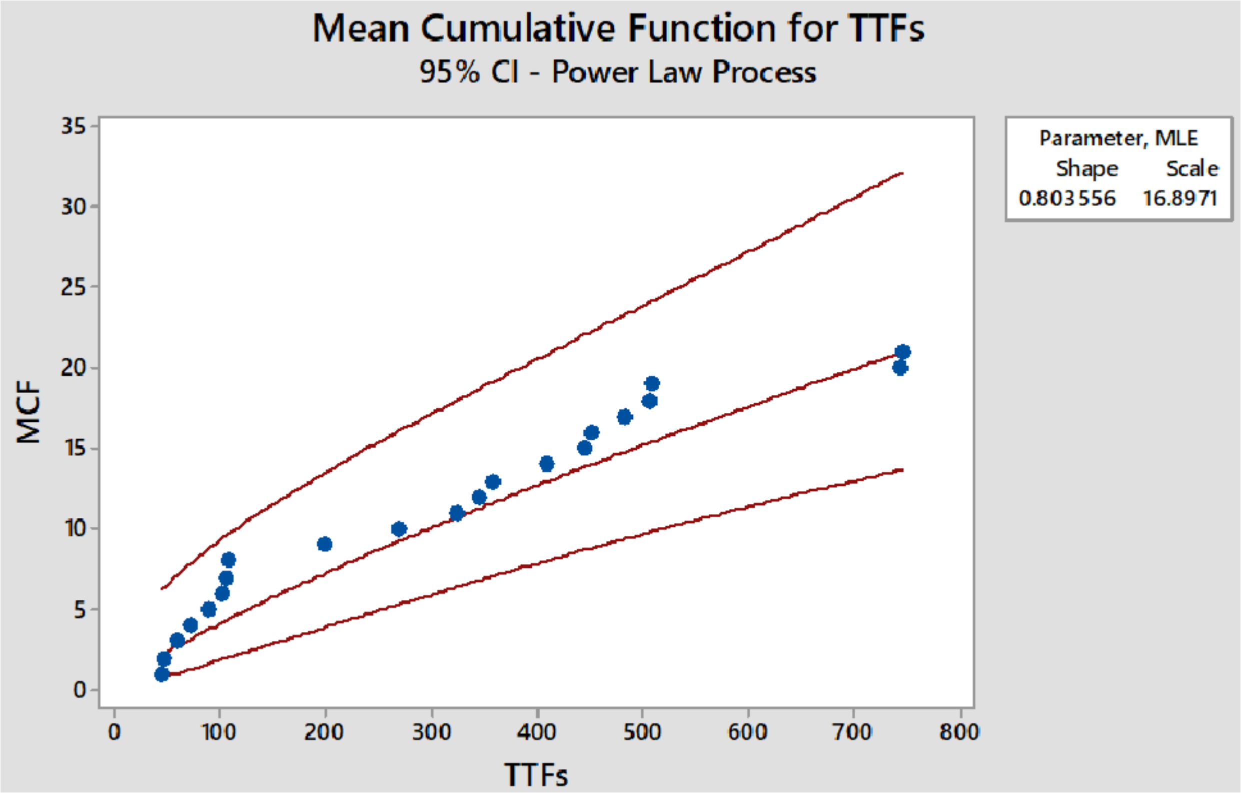
Recloser trip – grid event





- Highest probability of recloser shutting down all inverters (entire system) at 125 days
- Operator can remotely reset the recloser. The highest probability of repair is around 1 hour after the event

Evaluating failure or ‘trip’ rate for reclosers



What does the MCF say about the failure, is it becoming more or less frequent?

1134 failures per 1M hours. MTBF ~ 34.56, *if* failure rate is constant

Shape factor less than 1 indicates failure rate decreasing. 0.8 for this event, so failures occurring less frequently. Failure rate and MTBF are more appropriate for constant failure rates.

PV-RPM in SAM

- System Design Window

Same as any other SAM model

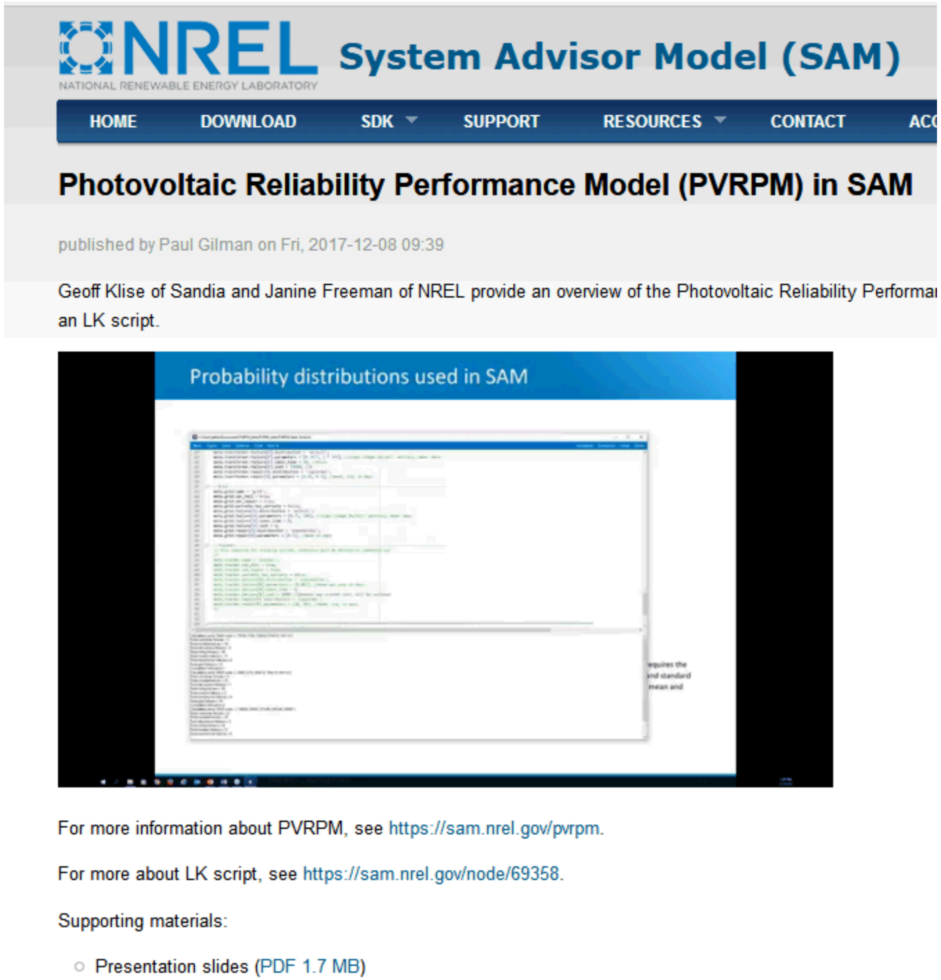
Components that can be simulated with probability distributions :

Modules	**AC Disconnects**
Strings	**Transformers**
DC Combiners	**Grid Impacts**
Inverters	**Trackers**

Output File

- *Power & Energy loss,*
- *costs,*
- *labor hours,*
- *LCOE,*
- *failures per component.*
- *Time series and annual results, per realization*

Recorded demonstration webinar



https://sam.nrel.gov/node/75555

O&M Cost Model – NREL / SunSpec

Sandia National Laboratories

Evaluates whether service cost is less than expected energy loss based on probability of failure. Ties PM to potential failure event

Subcomponent name:

Failure mode:

1. Failure distribution (uniform, Weibull, Lognormal, Poison)
2. Expected outage time (detection time + service time or replacement time)
3. Product of 1 and 2 gives expected energy loss $$

1. Is this failure mode covered by warranty? (yes/no)
2. If covered by warranty, which costs and losses be reimbursed? (material, labor and/or energy loss?)

1. Identify O&M or PM activity associated with this failure mode
2. Calculate costs (already existing in the worksheet)

SunSpec PV O&M Cost Model Web Application

- Dashboard
- User Accounts
- Reports
- Plant Groups
- Plants
- Cost Models
- Services
- Labor Rates

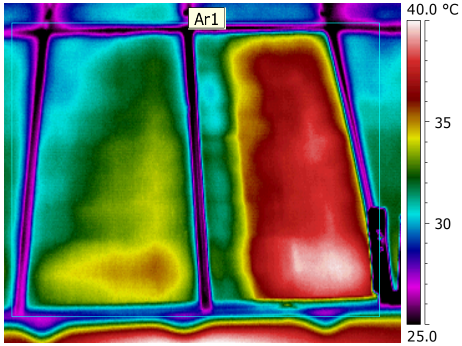
Reports

Plant - South Valley, Cost Model - Residential Rooftop

Summary View | Detailed View | Failure Mode Analysis

Service Type Name	Service Name	Failure Mode	Cost of Failure	MLE (Expected) Cost of Failure				
				Year 1	Year 2	Year 3	Year 4	Year 5
Inverter Inspection	Default	Power Electronics Failure Covered by warranty	$5788.32	$0.00	$11.29	$89.74	$297.33	$680.15
Inverter Inspection	Default	Power Electronics Failure Not covered by warranty	$7194.48	$0.00	$14.04	$111.54	$369.57	$845.37
Reboot Inverter	Default	Firmware malfunction/failure	$0.39	$0.08	$0.08	$0.08	$0.08	$0.08
Reboot Inverter	Default	Firmware malfunction/failure	$270.76	$0.00	$131.75	$199.39	$234.12	$251.95

If cost of service is below the maximum likelihood estimation of the energy lost, then it may be a good business decision to perform the specific PM event



Thank You

gklise@sandia.gov

U.S. DEPARTMENT OF ENERGY

SOLAR ENERGY TECHNOLOGIES OFFICE
U.S. Department Of Energy

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.